Progress toward a comprehensive cloud-cleared AIRS-CrIS radiance assimilation strategy

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Outline

- Short summary of past, published work on AIRS
  - Impact on TCs and global skill, caused by adaptive thinning of AIRS cloud-cleared radiances (CCRs)
- Impact of AIRS CCRs on high latitude atmospheric dynamics
- Impact of AIRS CCRs on representation of high-latitude convective cyclones (Arctic, Antarctic, and polar lows)
- Expanding the adaptive thinning strategy to other sensors (CrIS and IASI)
  - Best impact on global skill and on TC analysis and forecast
- New experiments with the Hybrid 4DEnVar GEOS system
  - Focus on Hurricane Harvey (2017)

Recent past work: Two major findings

Published in August 2018, a new article summarizes the improvements obtained by assimilating *adaptively thinned AIRS cloud-cleared radiances* over *homogeneously thinned clear-sky radiances.*

Reale, O., E. McGrath-Spangler, W. McCarty, D. Holdaway, R, Gelaro, 2018: Impact of adaptively thinned AIRS cloud-cleared radiances on tropical cyclone representation in a global data assimilation and forecast system. *Weather and Forecasting, 33, 908-931.*

1) Cloud-cleared AIRS radiances are a substantial improvement over clear-sky radiances, but must be thinned more aggressively because of higher information content

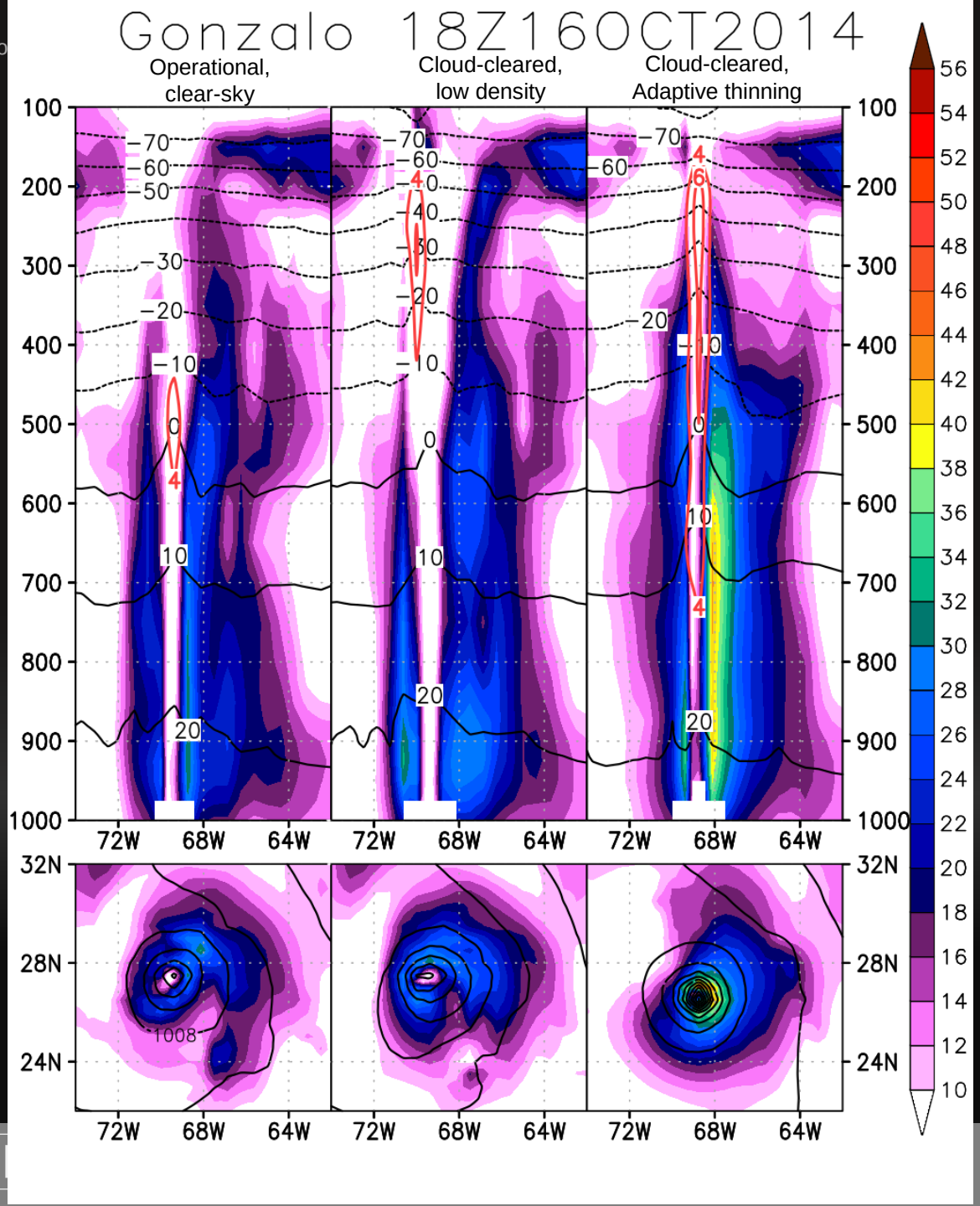
2) Assimilating *more data around TCs (small scale, strong gradients and rapid evolution)* and *less globally*, improves TC structure and intensity forecast, without damaging global skill.

Limits: only TCs with good AIRS coverage were affected; strong improvement on TC structure and intensity but negligible on forecast track; TCs with very short lifespans were difficult to improve

Experiments setup

GEOS, version 5.13, using 3DVar data assimilation, simulating boreal fall 2014

- OPS: Clear-sky AIRS radiances, version used quasi-operationally by the GMAO
- RAD: Clear-sky AIRS radiances, equivalent to operationally run version except with the vortex relocator turned off
- CLD3: Cloud-cleared AIRS radiances, globally assimilated at a lower density
- SThin2_CLD: Cloud-cleared AIRS radiances, adaptively thinned with lower global density, but higher density surrounding TCs using a `TC' domain that is activated with TC-vital or Best Track information
- SThin2CLD_SThin2CrIS_SThin2IASI: Cloud-cleared AIRS radiances AND clear-sky CrIS and IASI radiances assimilated using adaptive thinning, a comprehensive thinning approach for ALL hyperspectral infrared radiances



- H. Gonzalo (2014)
  - Vertical cross section: Wind magnitude (shaded), Temperature (°C, black), Temp. Anomaly (°C, red)
  - 850 hPa winds (shaded), slp (contours)

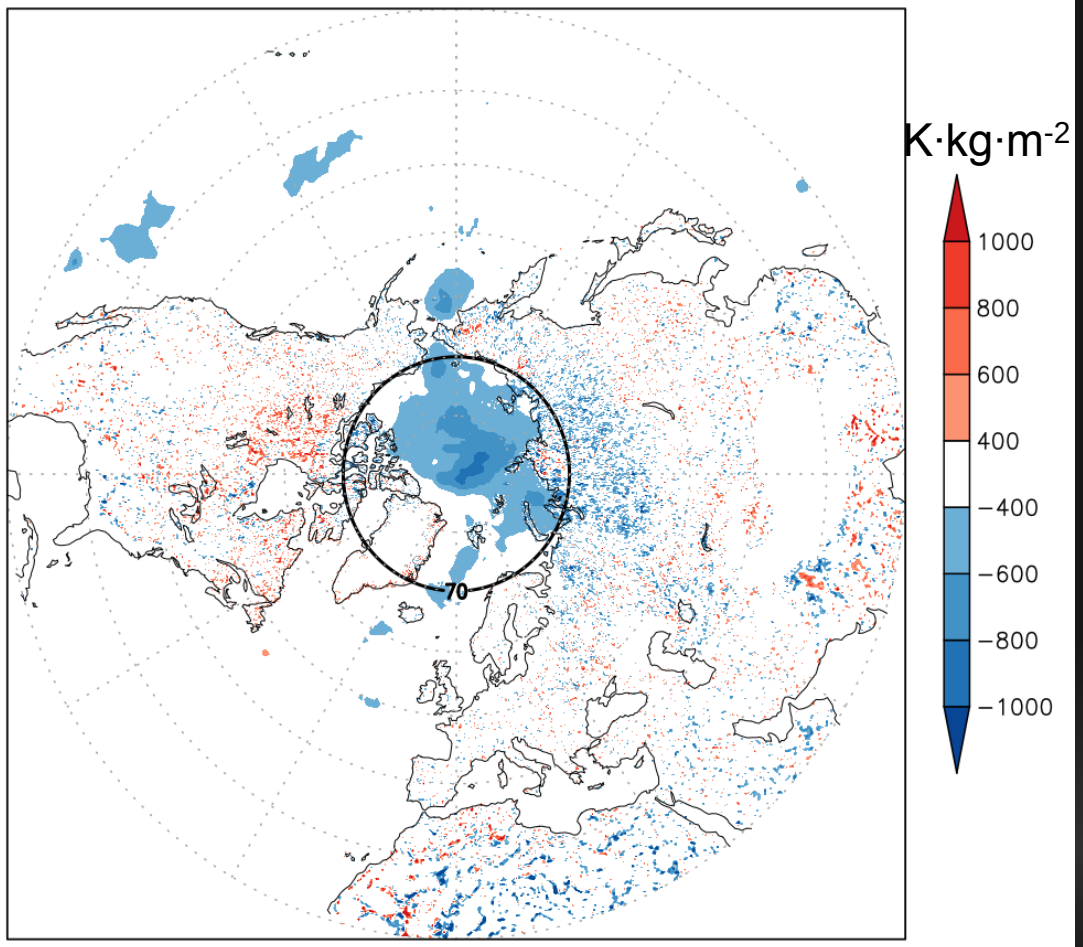
Adaptively thinned, cloud-cleared radiances produce large improvements in vertical and horizontal structure. Specifically: more compact scale, stronger wind speeds, lower minimum pressure, stronger warm core, at no expense to global forecast skill

Impact of cloud-cleared AIRS radiances on high latitudes

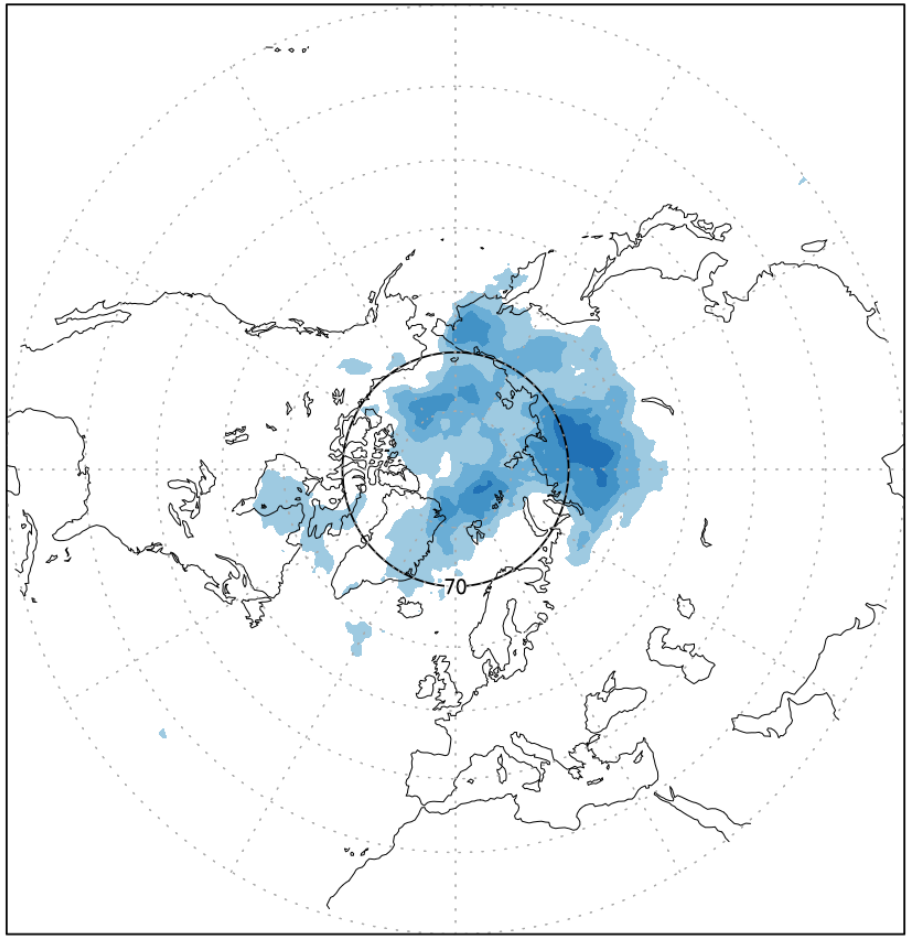
- The Arctic region is extremely data scarce and low-level stratus clouds limit the assimilation of clear-sky radiances. Therefore, it appears extremely sensitive to the assimilation of AIRS CCRs
- The positive impact on mid-latitude forecast skill is investigated with a plausible cause found
- A large and persistent temperature anomaly in the lower-mid troposphere is induced by the assimilation of CCRs, propagating to the mid troposphere in the form of a large geopotential adjustment

Nation

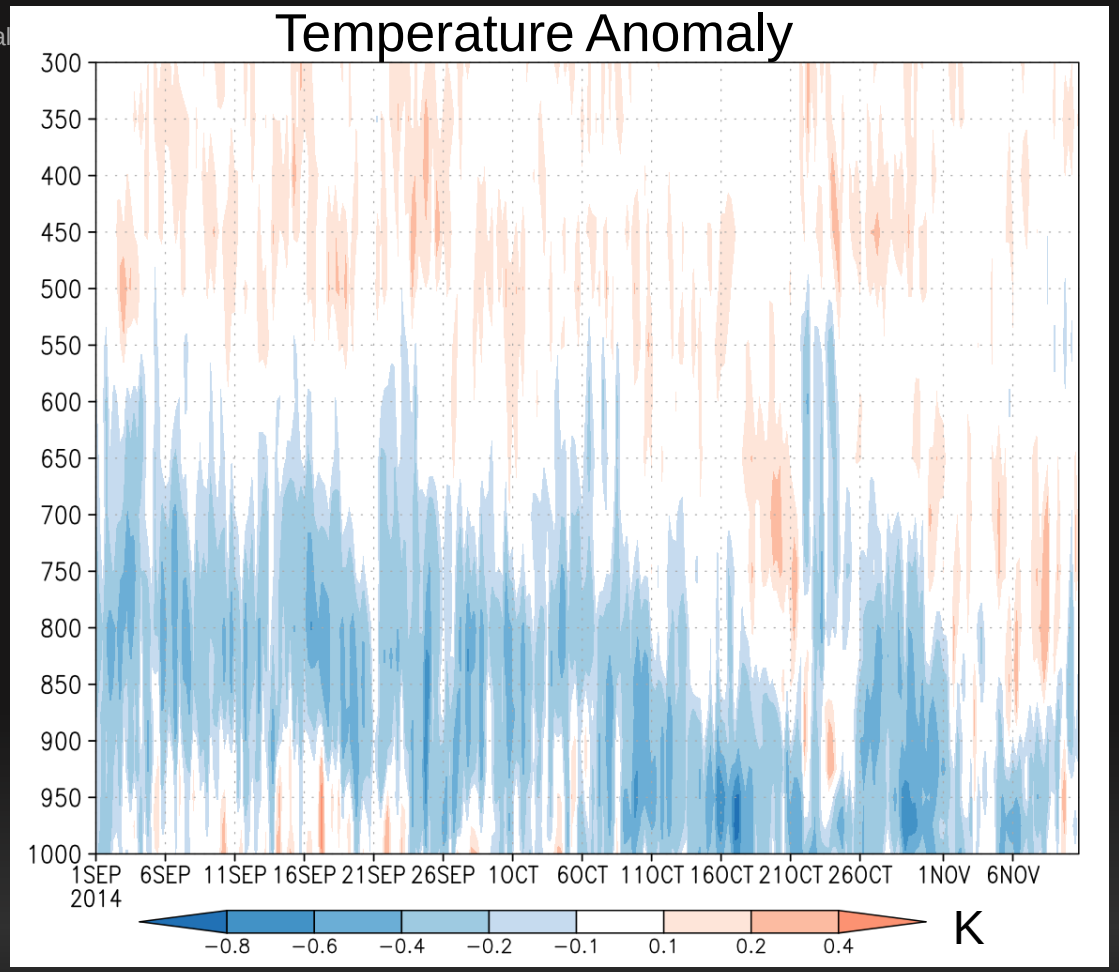
Vertically Integrated Temperature Anomaly

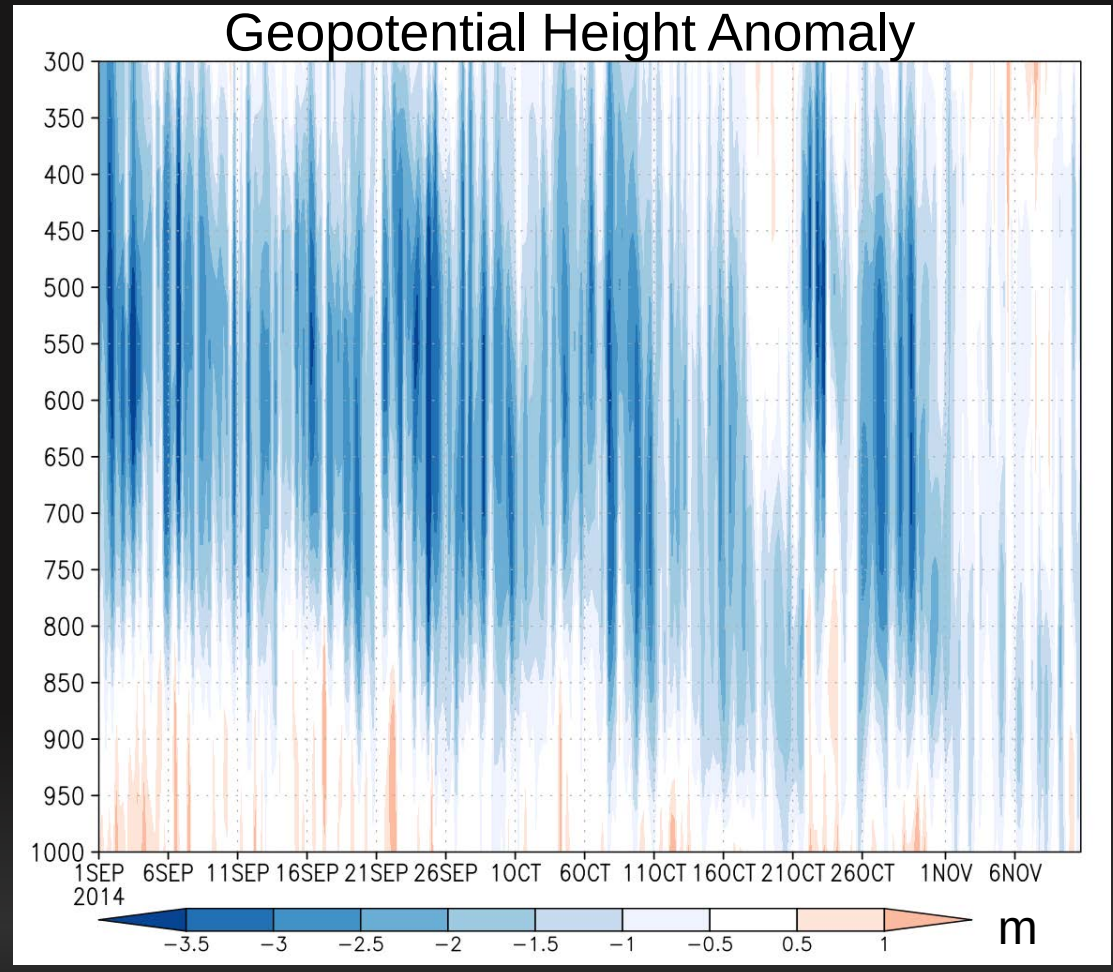


500-hPa Geopotential Height Anomaly



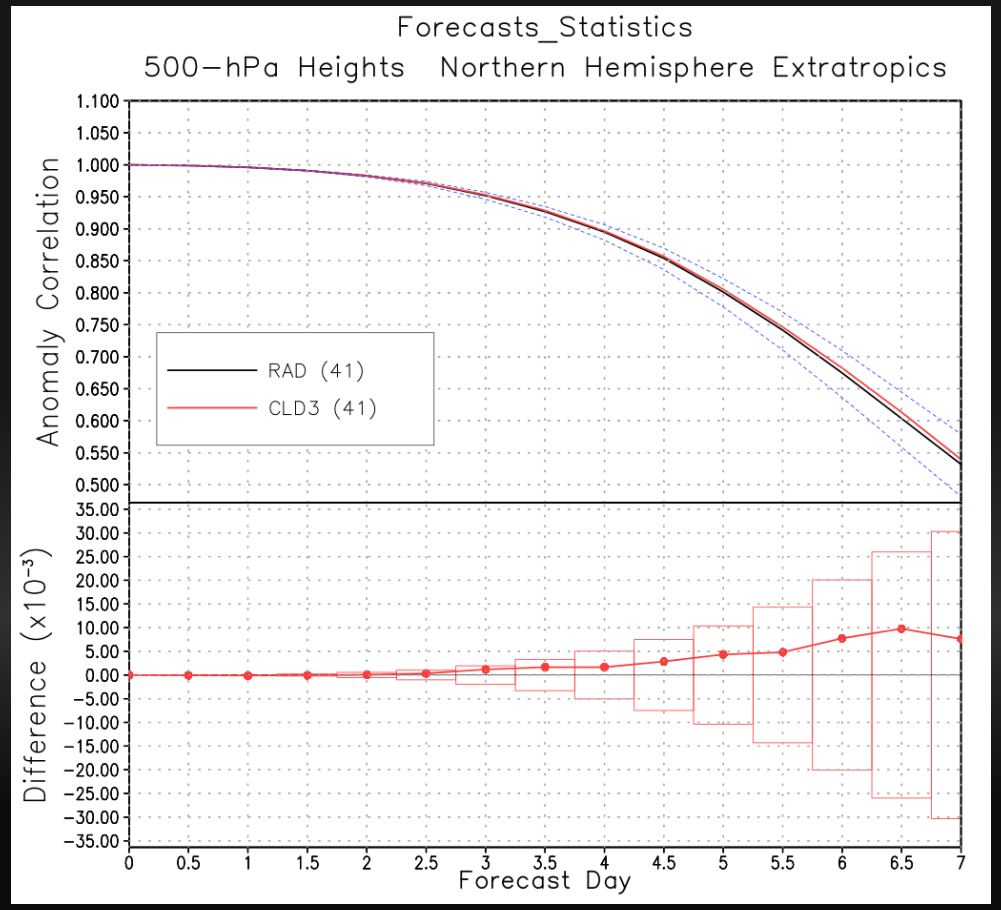
- *Cloud-cleared* minus *clear-sky* vertically integrated (sfc to 800-hPa) temperature and 500-hPa geopotential height anomalies in the analysis
- Large, spatially coherent temperature anomaly over Arctic induces negative mid- and upper-tropospheric geopotential height anomalies due to hydrostatic adjustment

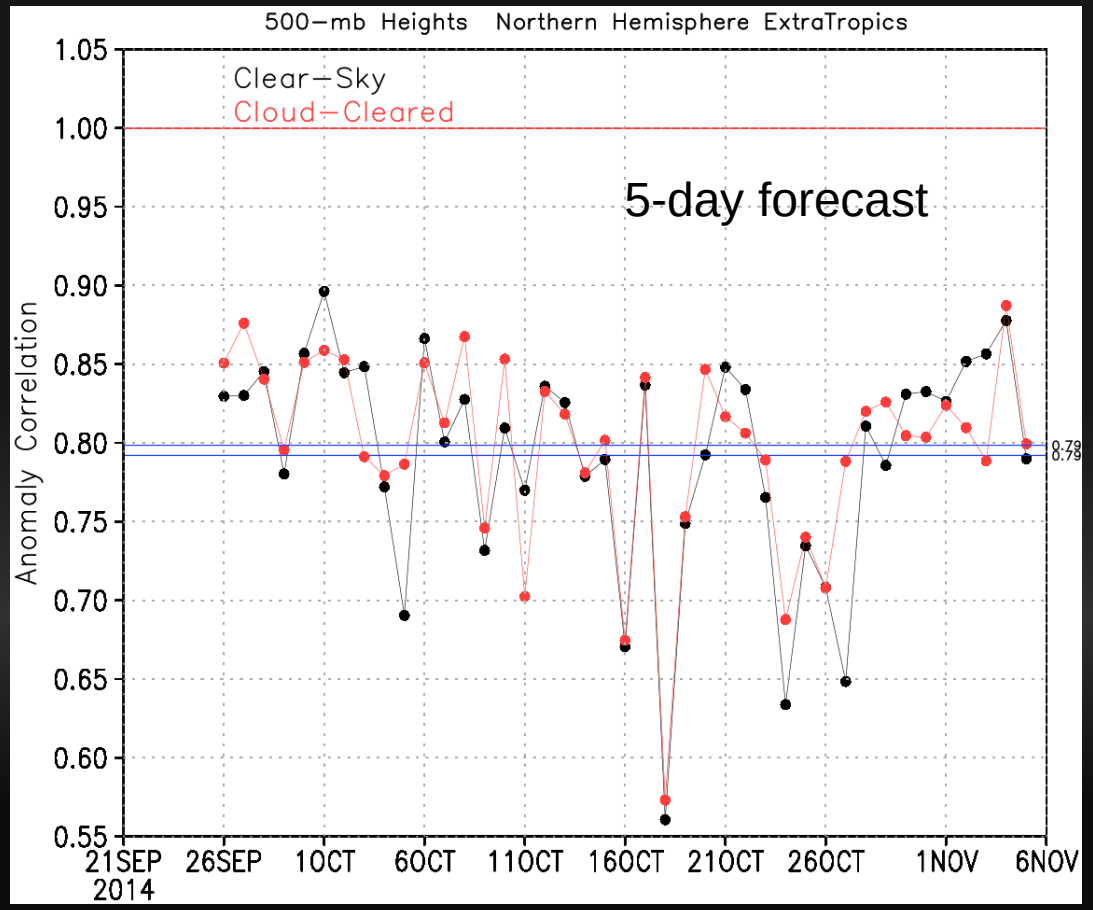


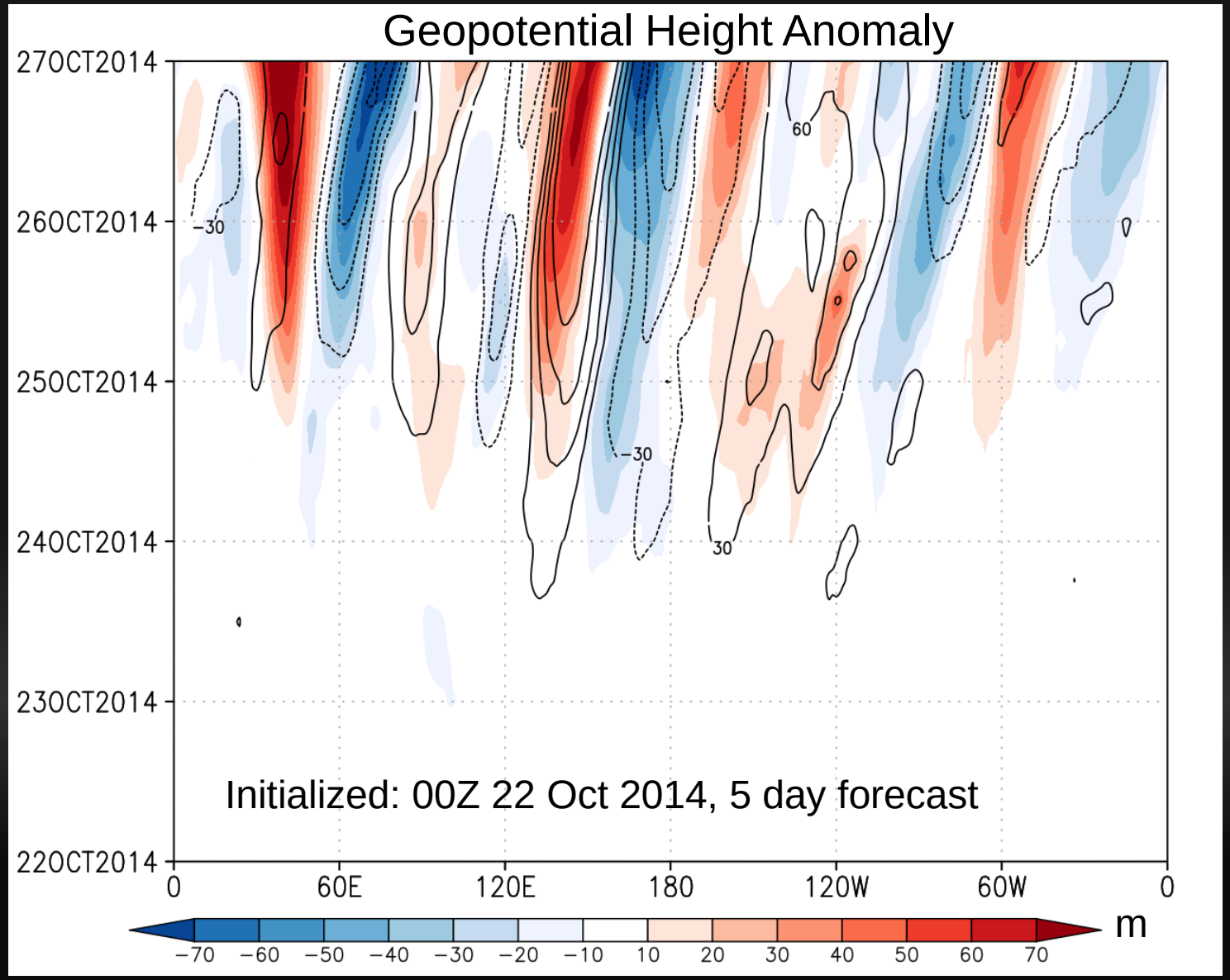


- *Cloud-cleared* minus *clear-sky* anomalies averaged 70ºN – 90ºN
- Persistent cooling over large area (over 15 million sq. km) and over 2 month time period produces lowering of geopotential height field
- The anomaly slopes downward, transitioning into the cold season
- Result of assimilating cloud-cleared AIRS radiances

NHE Forecast Skill



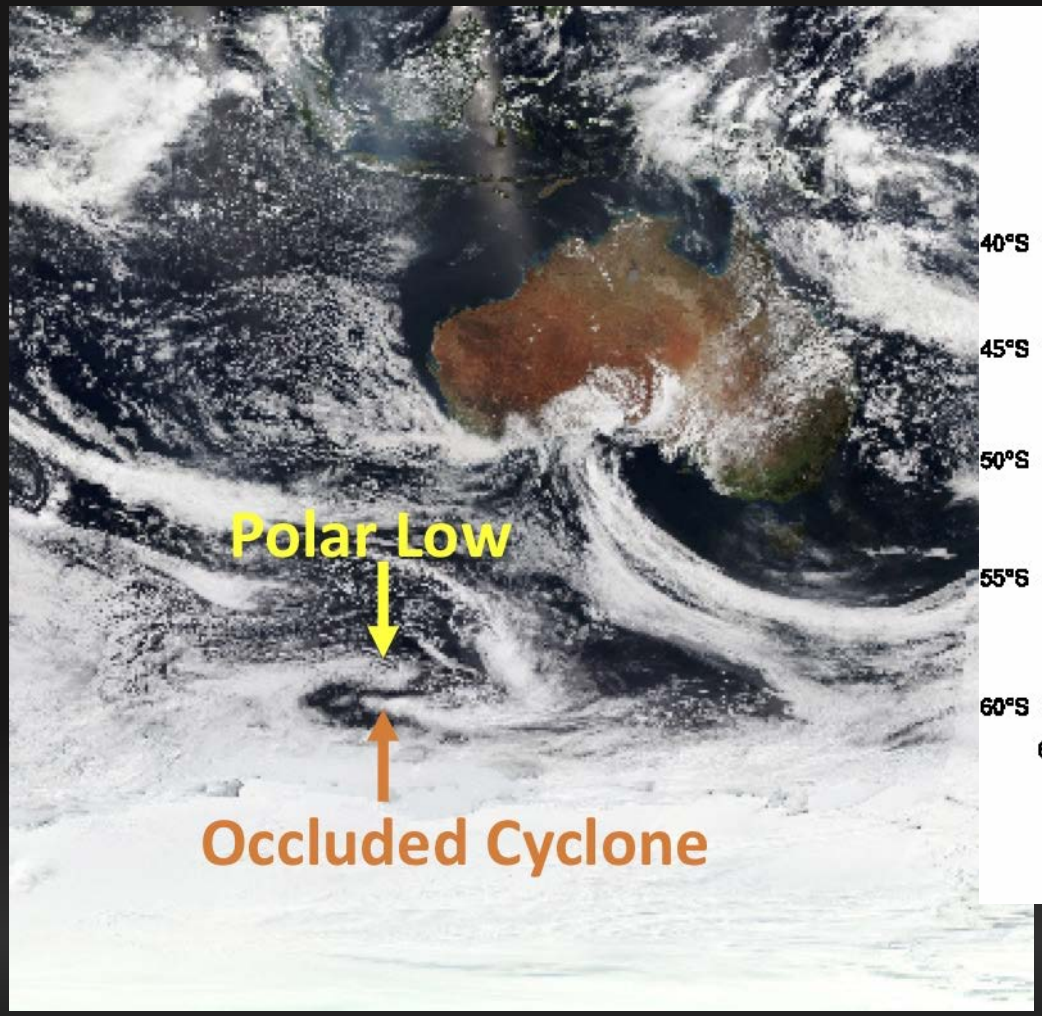


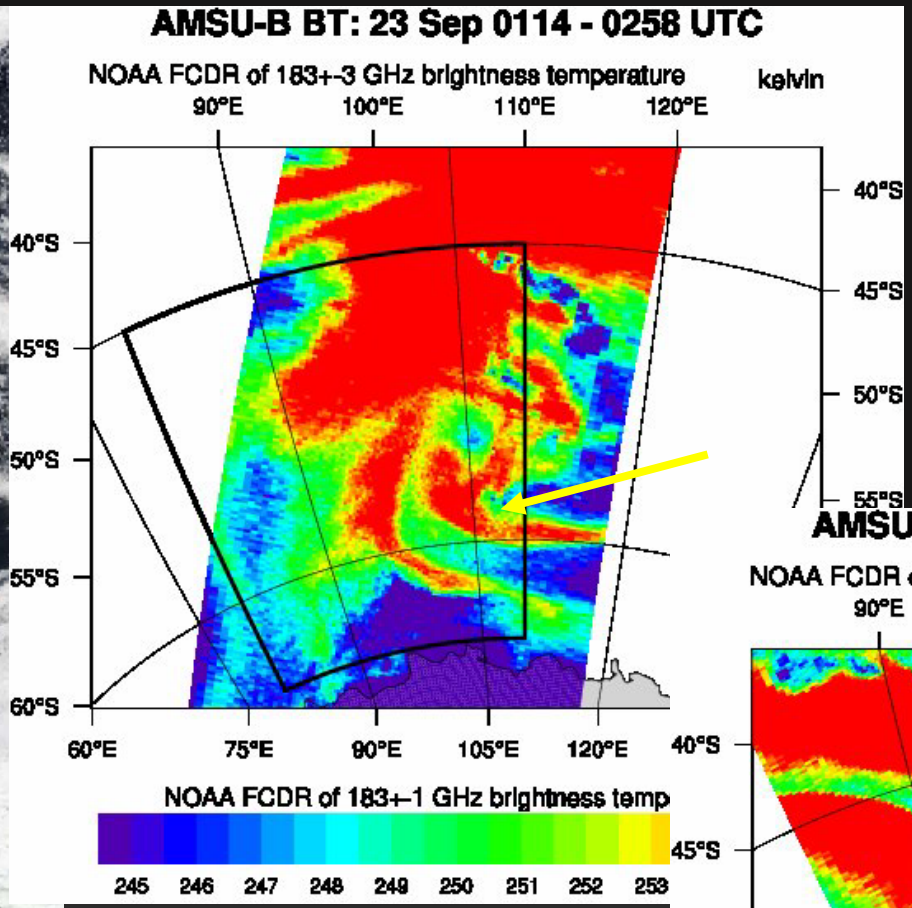


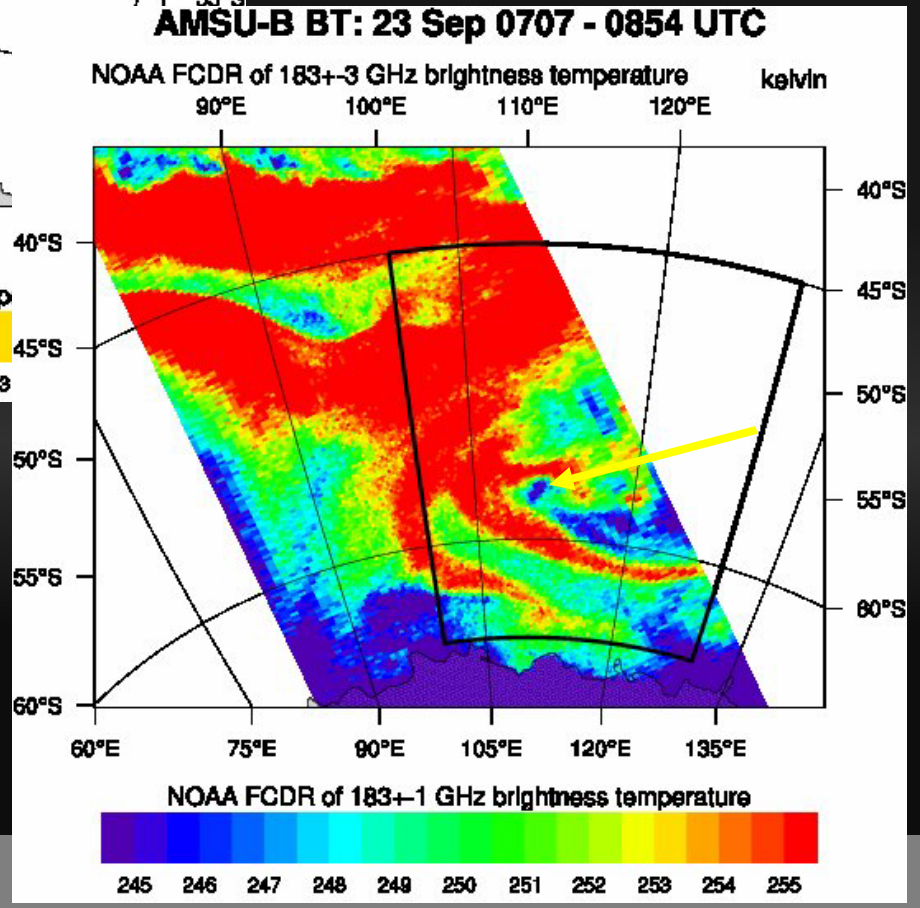
- Hovmöller diagram with 500 hPa geopotential height anomaly averaged from 40ºN – 80ºN
- Shaded: *cloud-cleared forecast* minus *clear-sky forecast*
- Contour: *NCEP analysis* minus *clear-sky forecast*
- Anomalies grow with time and travel with westerly mid-latitude waves
- Changes induced by cloud-clearing attempt to correct the forecast in the direction of the verifying analysis

Investigating Polar, Arctic, and Antarctic Lows

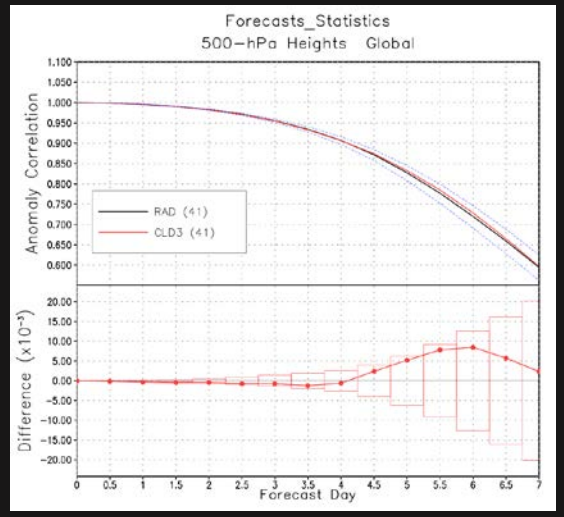
- Based on positive results obtained for TCs, we explore the sensitivity of Polar Lows (PLs) to the adaptive thinning methodology
- Unlike TCs, polar lows are generally not tracked in real time on a global scale (i.e., there is no TC vital-like information for PLs)
- This limits the operational applicability of the methodology as of now
- Adaptive thinning experiments are attempted to investigate whether the methodology could be applicable
- SThinPL_CLD: 'PL domains' (in which higher density AIRS cloud-cleared radiances are used around PLs) are constructed as TC domains, but based on satellite information (AMSU-B) only
- Results are promising and show strong sensitivity to assimilation of additional data in proximity to the storms

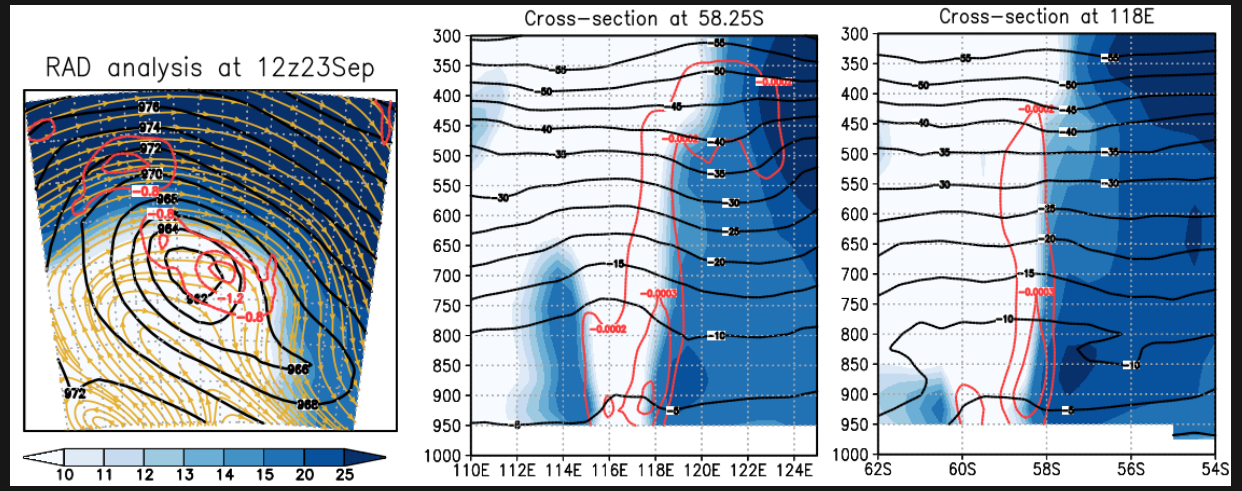






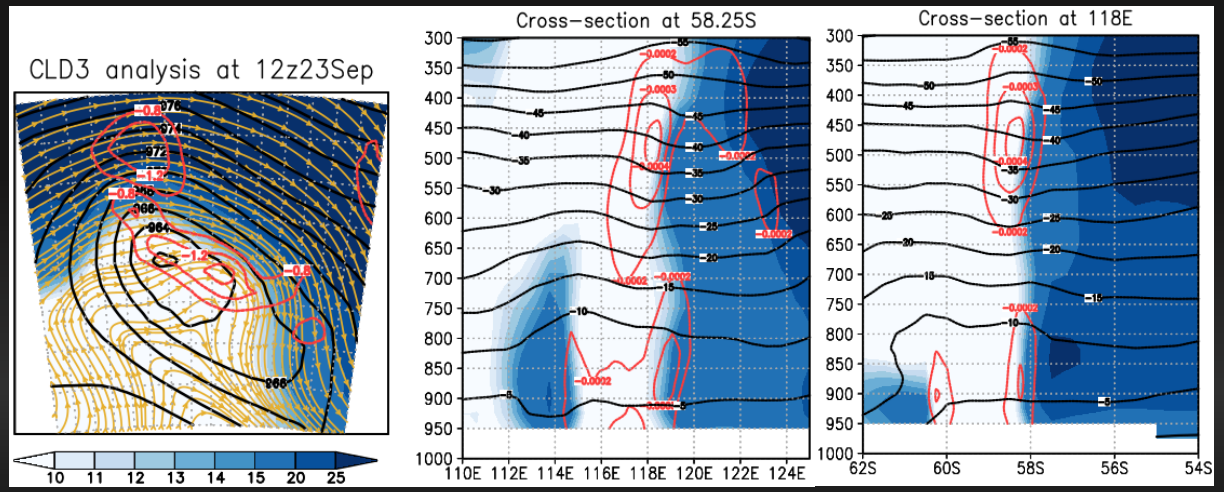
Satellite detection of polar low on 23 Sep. 2014

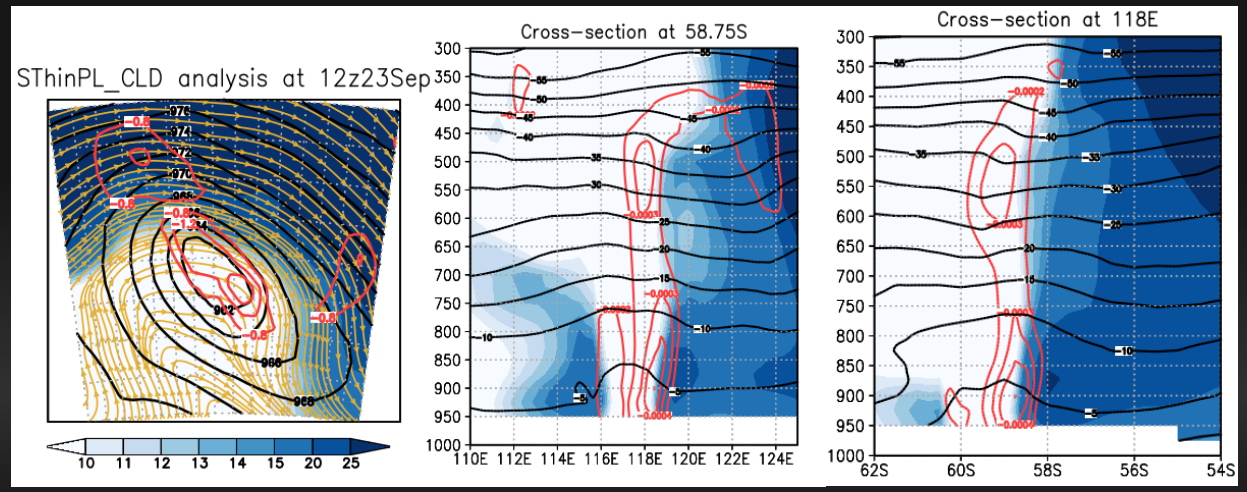




Horiz.: 300hPa winds (shaded), Vert. Integ. vorticity (red), slp (black)

Vert: Winds (shaded), vorticity (red), temperature (black)



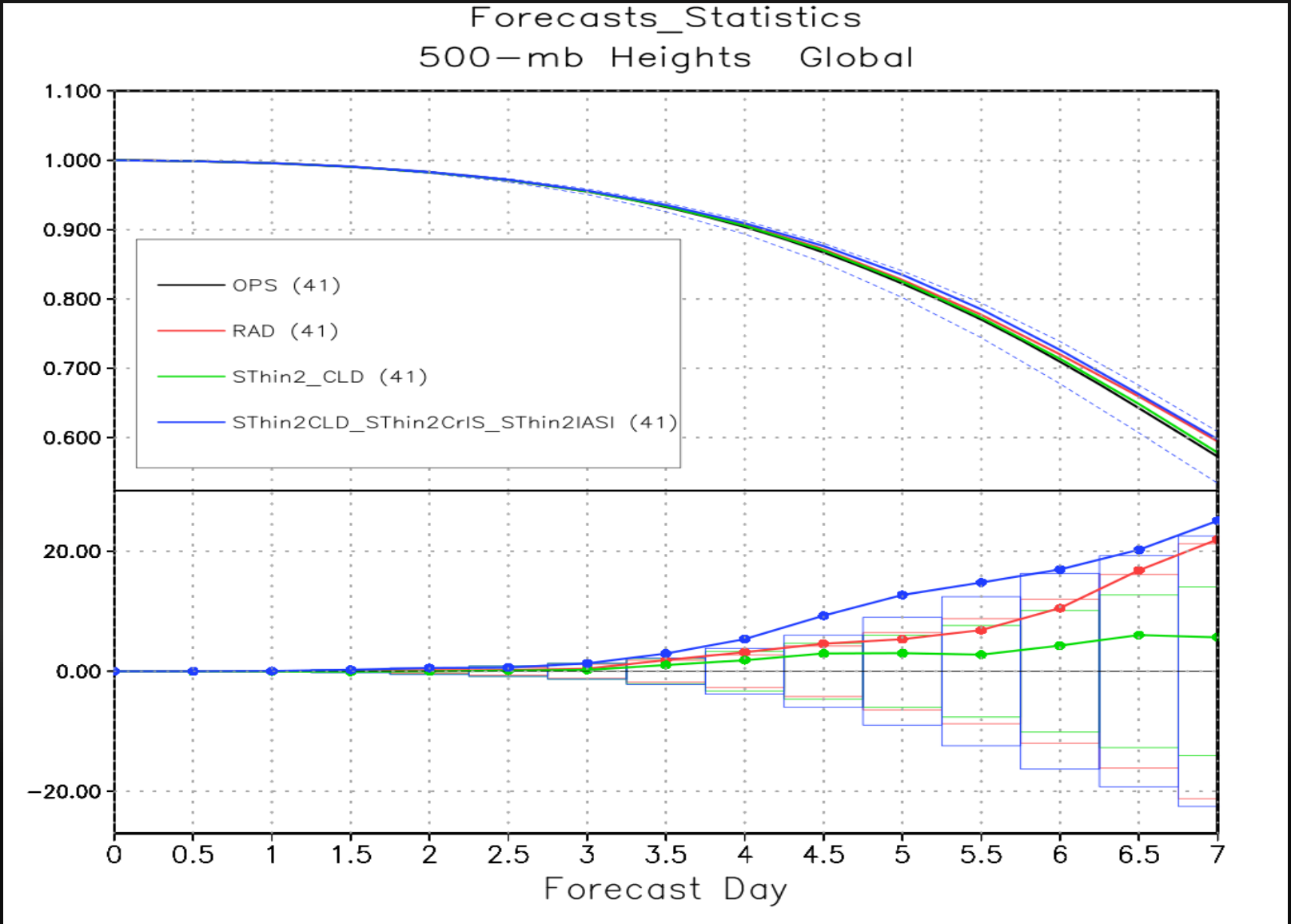


Maximum vertically integrated cyclonic vorticity and a vertically aligned eye-like feature occur when adaptively thinned AIRS CCRs are used around a polar low

Impact of a comprehensive adaptive thinning strategy for all IR sensors together

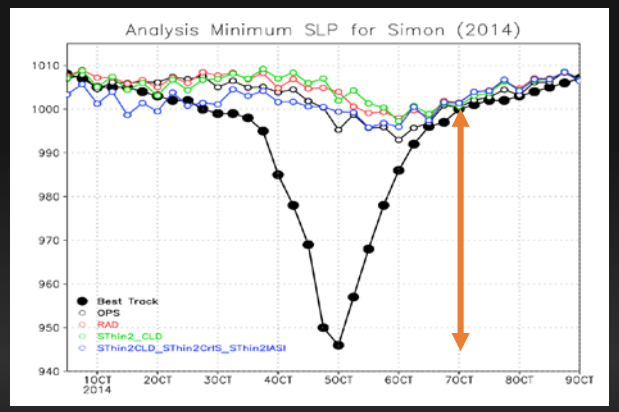
- Assimilation of low density AIRS CCRs brings a substantial improvement in global skill but negligible impact on TC structure
- Adaptively thinned AIRS CCRs bring a strong improvement on structure of many TCs, but negligible improvement on Global Skill
- However, when the adaptive thinning strategy is *simultaneously applied* to ***all*** hyperspectral sensors ***together***, global and TC representation both improve; even more TCs are positively affected

Global 500 hPa height anomaly correlation

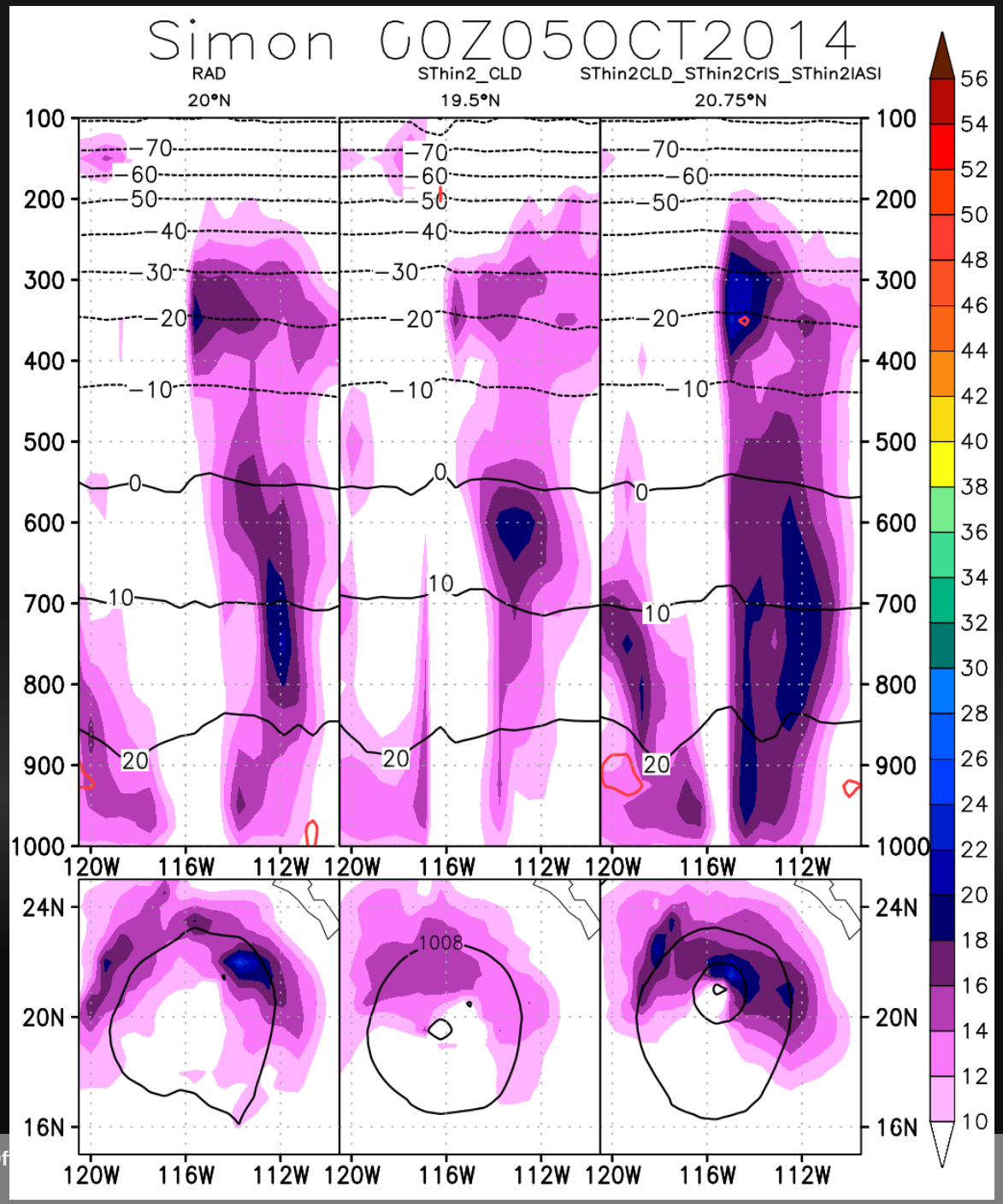


- A comprehensive, adaptive thinning approach for all hyperspectral infrared sensors, using cloud-cleared AIRS radiances, results in a statistically significant improvement in global forecast skill

H. Simon (2014)
East Pacific



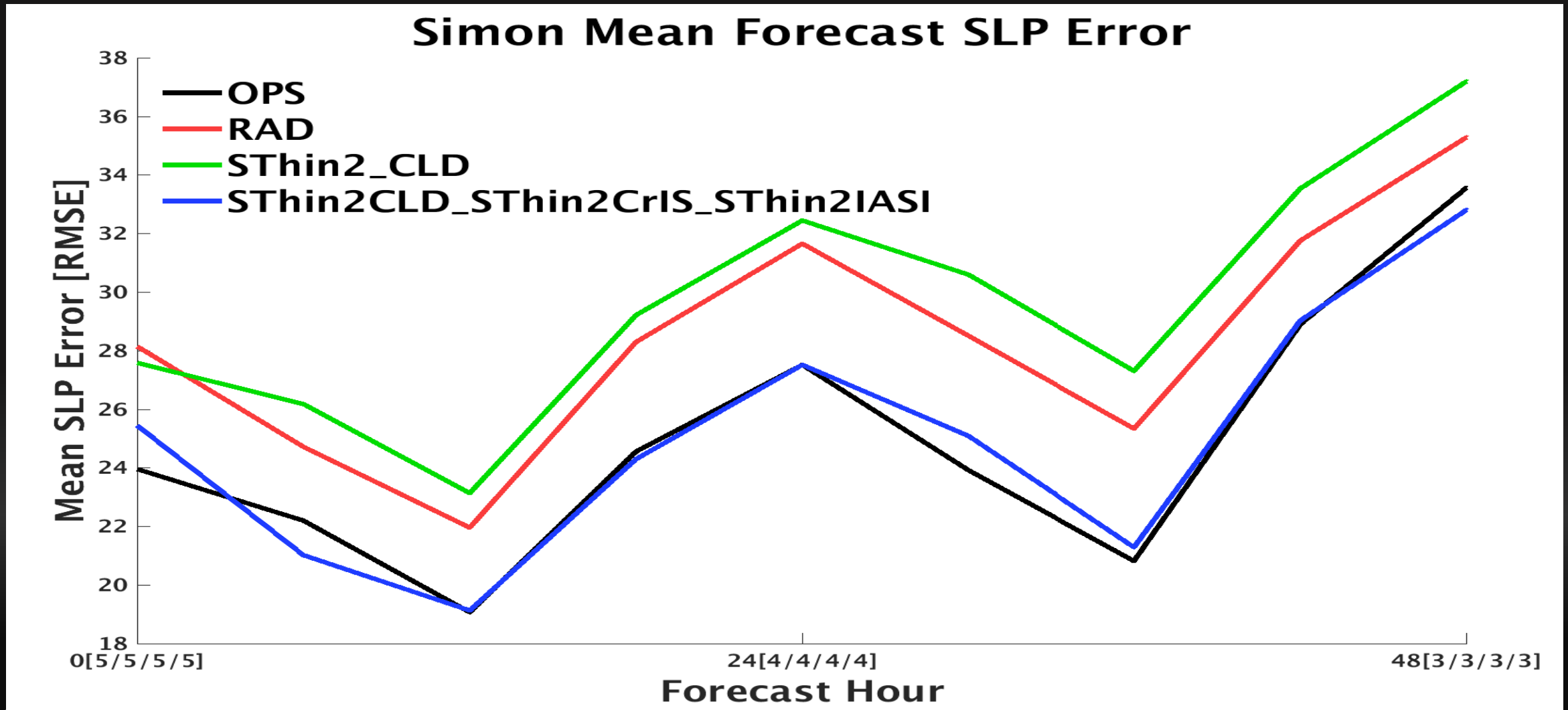
Impossibly difficult TC:
extremely small,
rapid deepening and
rapid dissipation



Vertical cross section
Wind magnitude (shaded)
Temperature (°C, black)
Temp. Anomaly (°C, red)

850 hPa winds (shaded)
slp (contours)

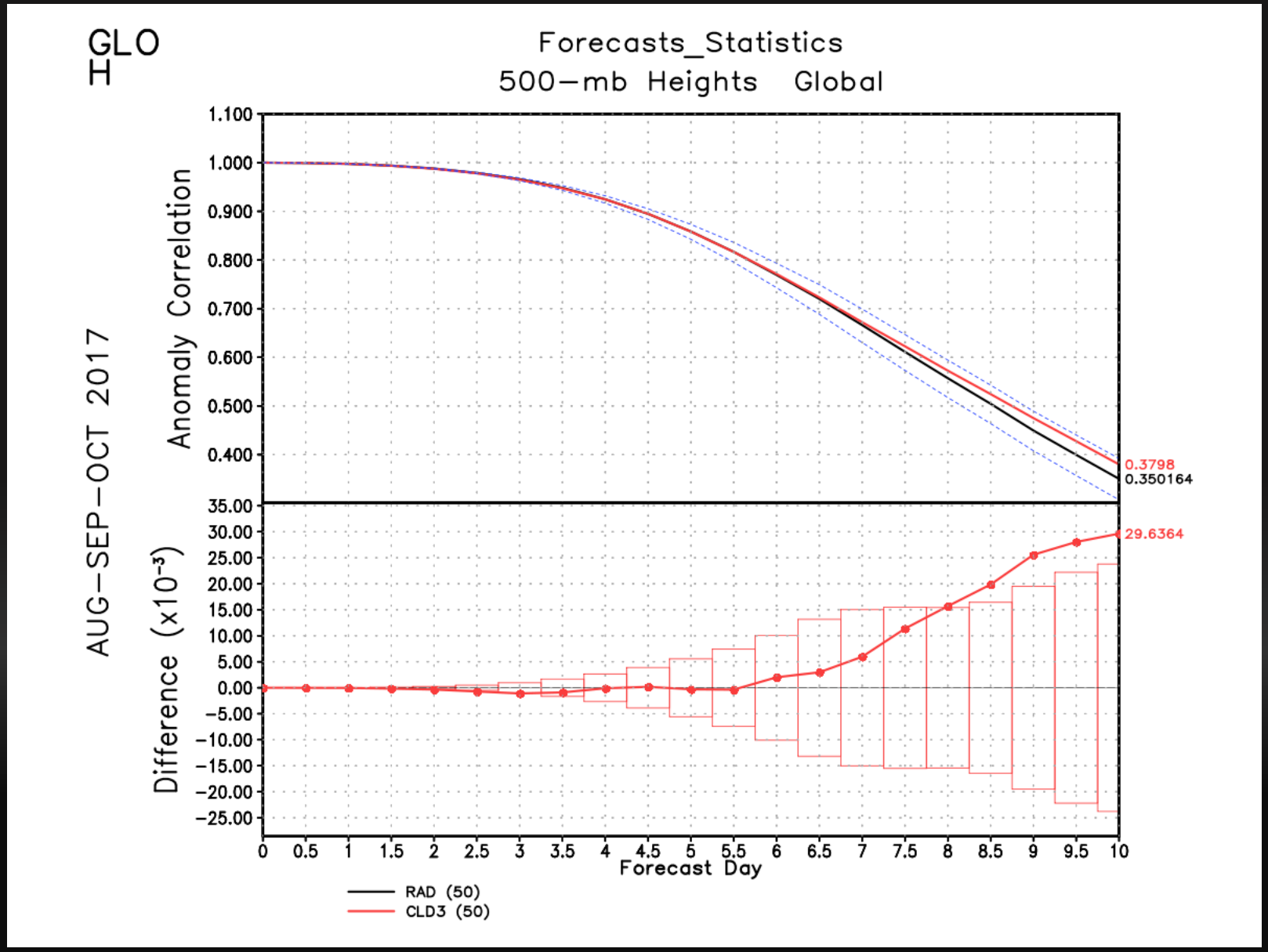
H. Simon intensity forecast



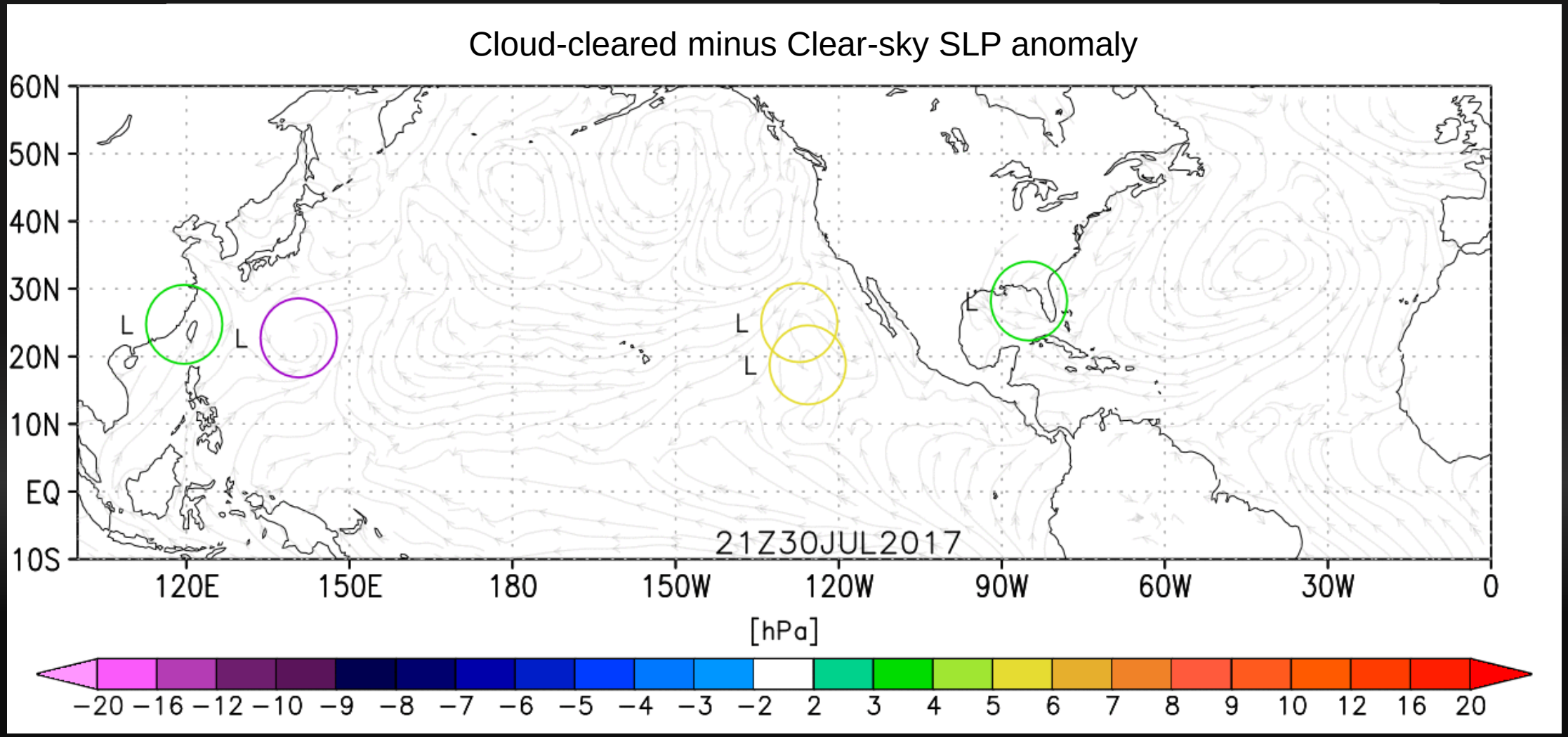
Intensity forecast for this difficult storm is identical to the one obtained with vortex relocator

Hybrid 4DEnVar experiments and results

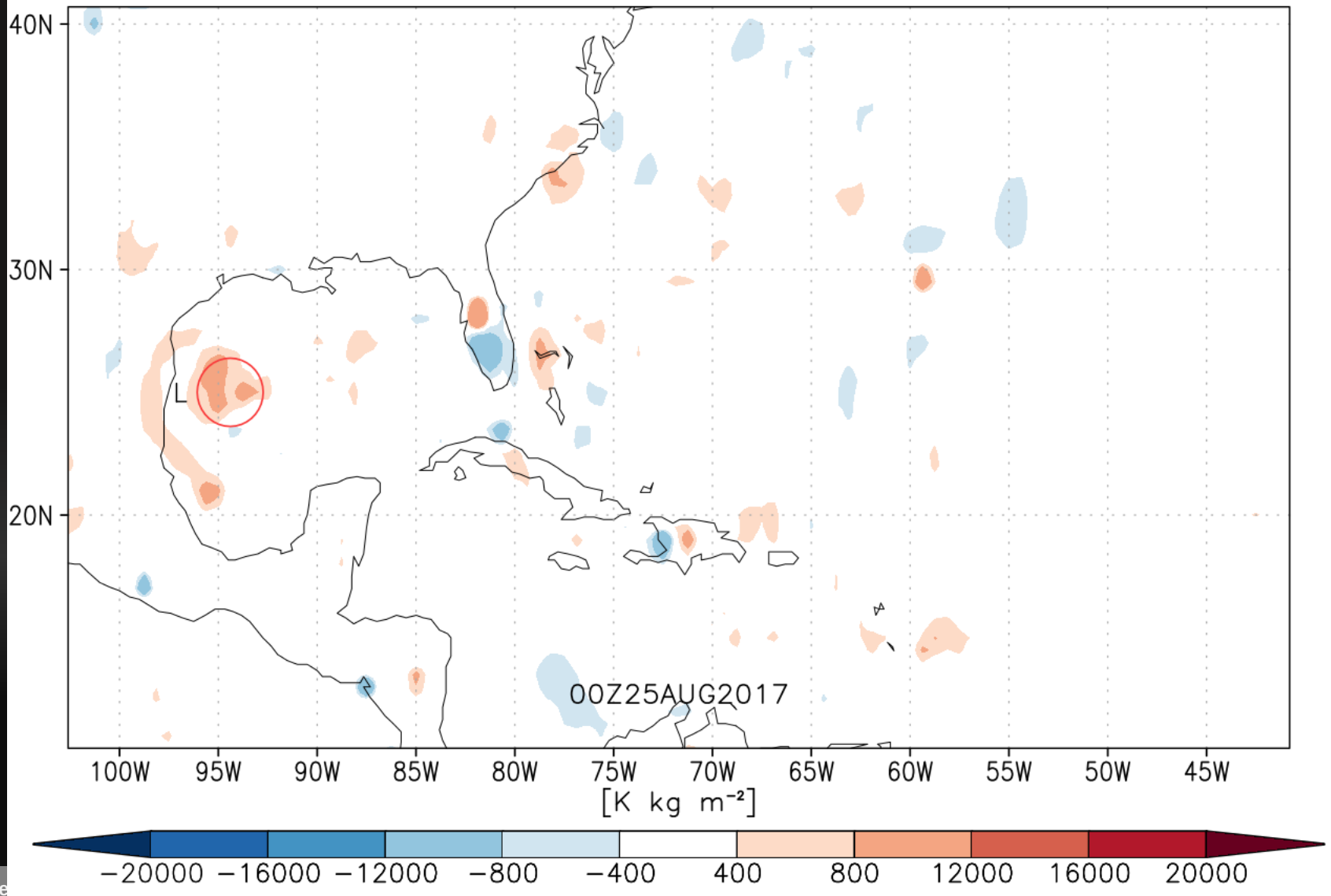
- GEOS, version 5.17 experiments, using hybrid 4DEnVar data assimilation, simulating boreal late summer – early fall 2017
- RAD: Clear-sky AIRS radiances, as used operationally
- CLD3: Cloud-cleared AIRS radiances, globally assimilated at a lower density (~1/3 of RAD)

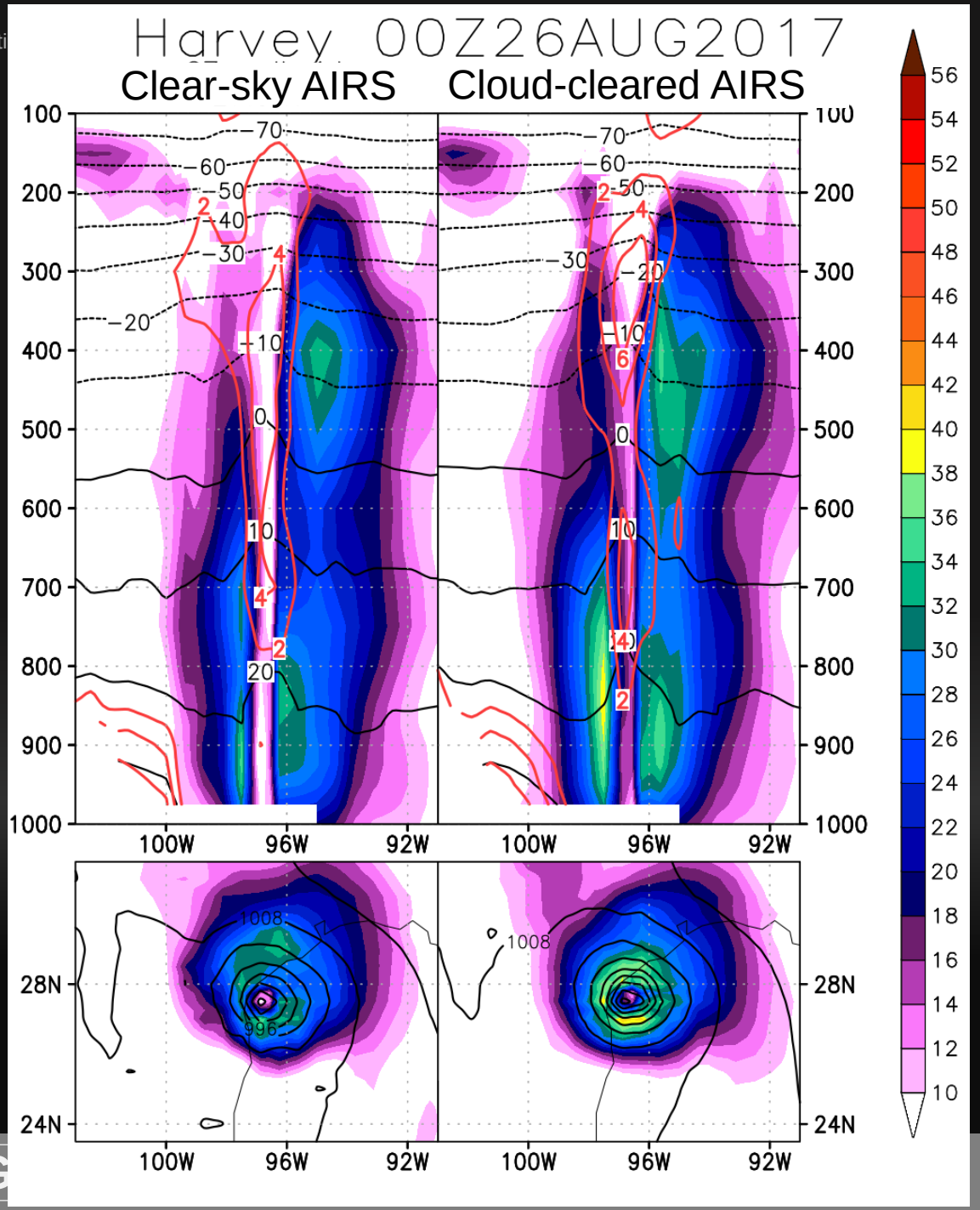


- Assimilation of cloud-cleared AIRS radiances, more aggressively thinned, does not degrade the global forecast skill and produces an improvement after 6 days

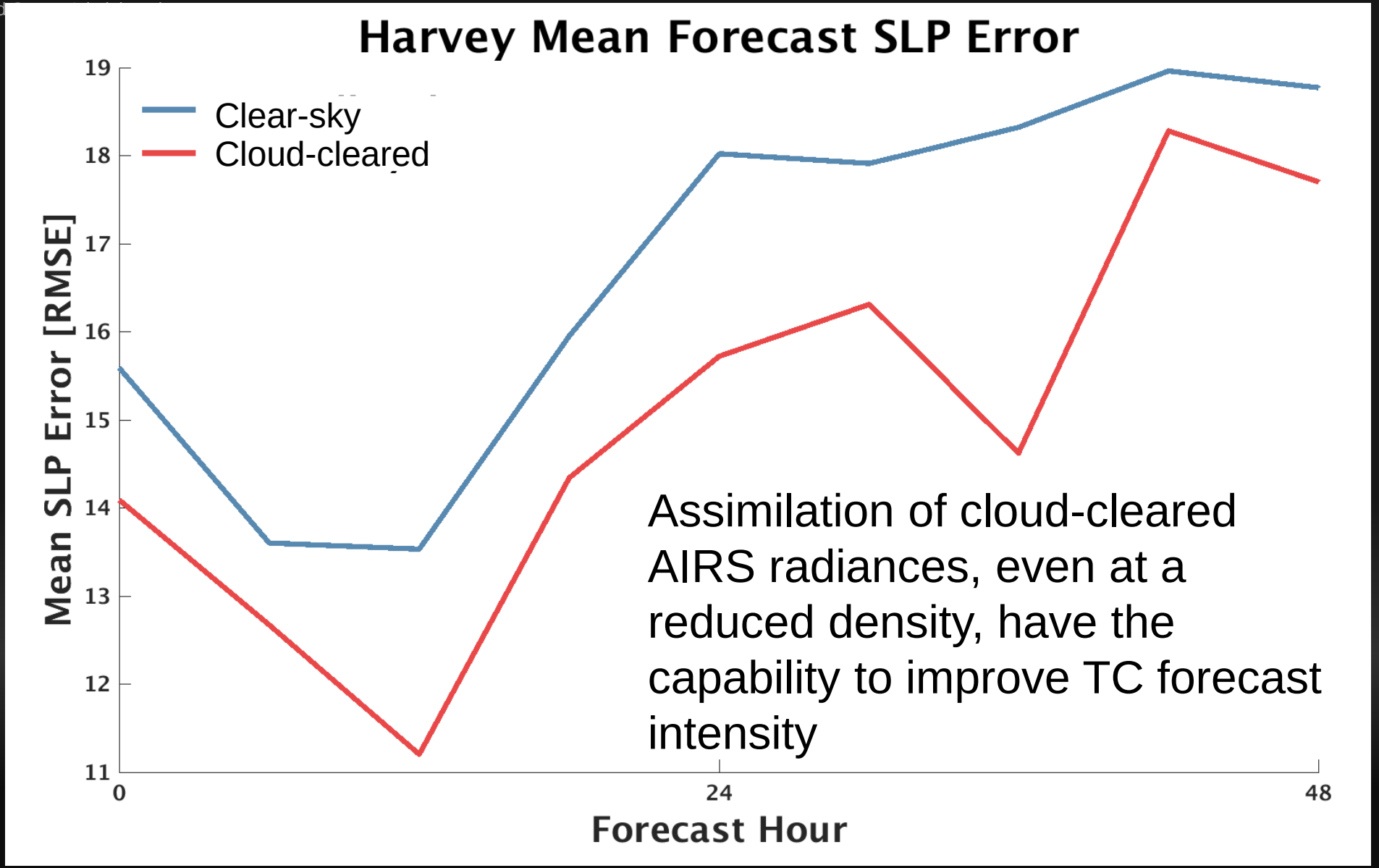

Cloud-cleared minus Clear-sky SLP anomaly
60N
50N
40N
30N
20N
10N
EQ
10S
120E
150E
180
150W
120W
90W
60W
30W
0
L
L
L
L
L
21Z30JUL2017
[hPa]
−20 −16 −12 −10 −9 −8 −7 −6 −5 −4 −3 −2 2 3 4 5 6 7 8 9 10 12 16 20

H. Harvey (2017) Cloud-cleared minus Clear-sky Vertically Integrated Temperature Anomaly (300 to 200 hPa)





- H. Harvey (2017)
  - Vertical cross section: Wind magnitude (shaded), Temperature (°C, black), Temp. Anomaly (°C, red)
  - 850 hPa winds (shaded), slp (contours)
- Increased warm core structure, stronger wind speeds and lower sea level pressure and an overall improvement in vertical and horizontal structure result from assimilation of cloud-cleared AIRS radiances assimilated at low global resolution


Harvey Mean Forecast SLP Error
Clear-sky
Cloud-cleared
Mean SLP Error [RMSE]
19
18
17
16
15
14
13
12
11
0
24
48
Forecast Hour
Assimilation of cloud-cleared AIRS radiances, even at a reduced density, have the capability to improve TC forecast intensity

Conclusions

- Previous work has shown the strong positive impact of assimilating adaptively thinned AIRS cloud-cleared radiances (CCRs) on TC representation, with no loss of global skill
- More recent findings show that the increase in mid-latitude forecast skill is caused by a strong sensitivity of the Arctic region to assimilation of AIRS CCRs. This causes a large negative lower tropospheric temperature anomaly in the Arctic, which induces a mid-upper tropospheric height anomaly that propagates to the mid-latitudes and improves the forecasts of individual waves
- Adaptively thinned AIRS CCRs also improve the analysis of *polar lows* (stronger vorticity columns, more pronounced warm cores, and better vertical alignment)
- A comprehensive thinning approach (which adaptively thins *all hyperspectral infrared radiances together*) results in improved global forecast skill and better TC representation than when applied to AIRS radiances alone
- Ongoing experiments with the newer Hybrid 4DEnVar data assimilation system continue to show the strong sensitivity of TC representation to assimilation of CCRs and appear very promising
- Future work will involve assimilation of CrIS CCR and further exploring the sensitivity to adaptive thinning in the Hybrid 4DEnVar system

Acknowledgements

Thanks to:

Dr. Tsengdar Lee for current support through grant 80NSSC18K0927 ”Using AIRS and CrIS data to understand processes affecting TC structure in a Global Data Assimilation and Forecasting Framework (2018-2021)” (PI: Dr. O. Reale)

Dr. Ramesh Kakar for past support through previous grants NNX11AK05G and NNX14AK19G “Using AIRS Data to Understand Processes Affecting Tropical Cyclone Structure and Extreme Precipitation in a Global Data Assimilation and Forecasting Framework”(2011-2014, 2014-2018), PI: O. Reale

Dr. Chris Barnet for his leadership on the development of cloud-cleared radiance algorithms.

Dr. Tsengdar Lee for generous allocations of NASA High End Computing resources (NCCS)

AIRS team at JPL and the Sounder Research Team at NASA GSFC

GES DISC for their outstanding service to the community

AIRS-related articles published by this team

Reale, O., J. Susskind, R. Rosenberg, E. Brin, E. Liu, L. P. Riishojgaard, J. Terry, J. C. Jusem, 2008: Improving forecast skill by assimilation of quality-controlled AIRS temperature retrievals under partially cloudy conditions. Geophysical Research Letters, 35, L08809, doi:10.1029/2007GL033002.

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Reale, O., E. McGrath-Spangler, W. McCarty, D. Holdaway, R, Gelaro, 2018: Impact of adaptively thinned AIRS cloud-cleared radiances on tropical cyclone representation in a global data assimilation and forecast system. Weather and Forecasting, 33, 908-931.